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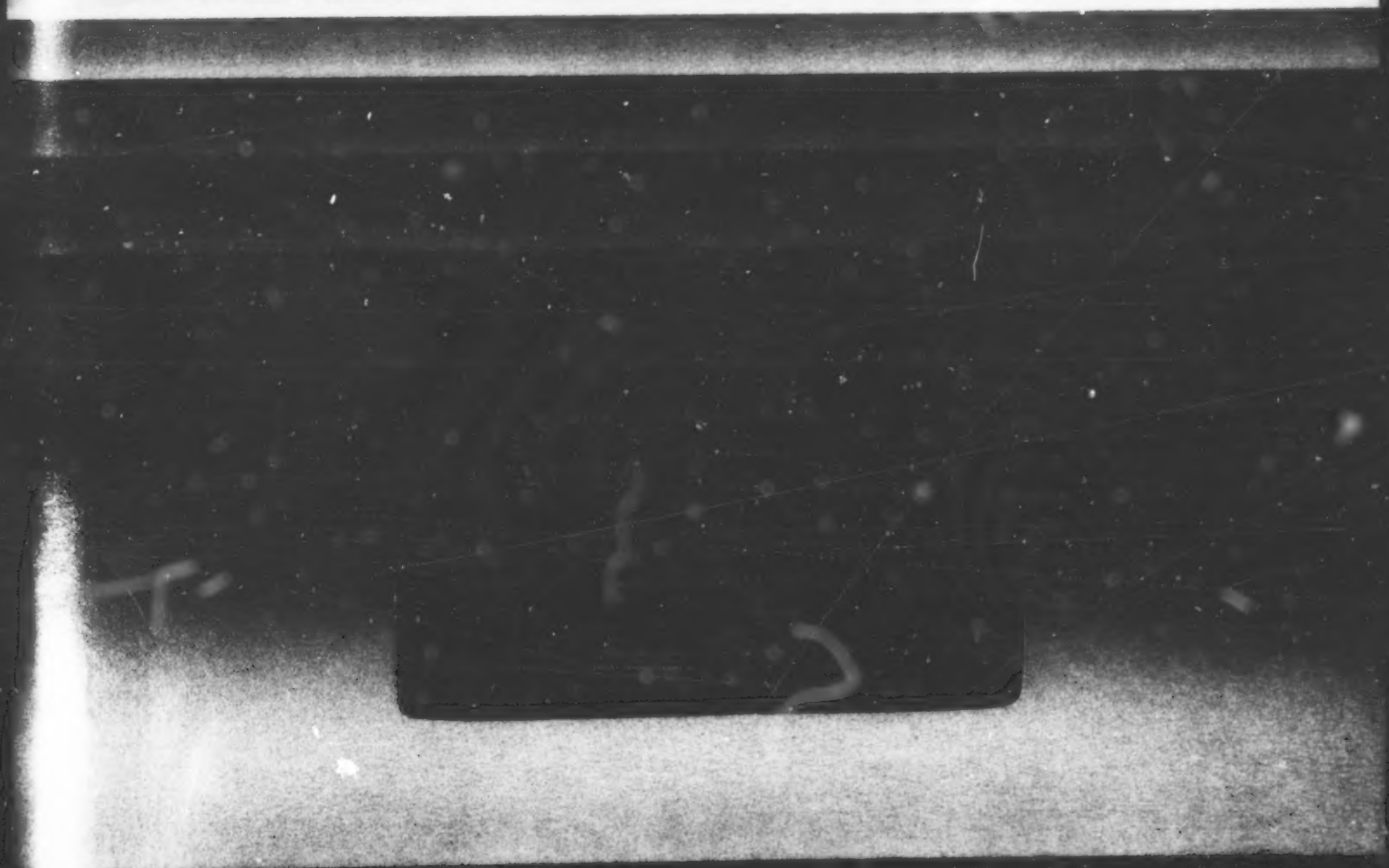

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LAKE REGIMES, MACKENZIE DELTA, N.W.T. 1985

CS-87005

~~NHRI Internal Planning Report No.88008~~

October 1988

90-05374/

ABSTRACT

Research on the hydrological regime of lakes and channels located in three areas along the eastern sector of the Mackenzie Delta, N.W.T., was conducted from April to September 1985. Several different hydrological processes dominated the hydrological regime of Delta lakes and channels at different periods throughout the year. Lake water levels were also controlled by some of the geomorphological features of the Mackenzie Delta.

The dominant hydrologic process is backwater flooding as a result of ice jam formation during spring break-up. Lake closure elevation also plays an important role in the hydrologic regime of lakes throughout the year. During the spring flood, lake water volumes increased by as much as 334%. Once ice jams failed, water loss was as high as 590 mm/d over several days. During the open water period, most lakes had a negative water balance which in many cases was higher than the total annual precipitation for the Delta. Perched lake water levels are controlled by the rate of evaporation during the summer. In 1985 the rate of evaporation was between 3.1 mm/d and 5.3 mm/d. This process accounted for up to 85% of the water lost, with the remaining 15% lost through outflow. Connected lakes, however, lost up to 85% of their water through outflow to the Delta channel system at an average rate of 18.1 mm/d. The remaining 15% was attributed to evaporation.

The negative annual water balance of lakes in the Mackenzie Delta underlines the importance of break-up and spring flooding to hydrological regime of these lakes. River regulation could result in a significant modification to the hydrologic regimes of Delta lakes.

RESUME

Cette étude avait comme but d'examiner et d'expliquer le régime hydrologique des lacs et chenaux répartis dans trois régions, le long du secteur est du delta du Mackenzie. Cette recherche a étè éffectuée entre avril et septembre, 1985. Durant cette periode, de nombreuses processus hydrologiques influencent le niveau d'eau des lacs et chenaux du delta. Le niveau d'eau des lacs fût aussi régis par les caractéristiques géomorphologiques du delta.

Pendant la débâcle printanière, plusieurs embâcles de glaces se produisent, provoquant de graves inondations. Le régime hydrologique des lacs dépend de la crue printanière, le processus intégrale à leur régénération annuelle. L'élévation des seuils des lacs est aussi un mecanisme très important au régis du niveau d'eau dans les lacs durant l'été.

En 1985, après la formation d'un embâcle sur un des chenaux principaux, le volume d'eau dans les lacs de la region ont augmentées par autant que 334%. Après la faillite de l'embâcle de glace, le niveau d'eau des lacs s'abassait par autant que 590 mm/j, pendant plusieurs jours. La balance d'eau des lacs durant l'été était négative et pour la plupart des lacs cette balance négative était supérieure au montant d'écoulement et de précipitation que reçoit ces lacs annuellement. Pendant l'été, le niveau d'eau des lacs perchées est controler par la quantité d'évaporation. Cette quantité a varié entre 3.1 mm/j à 5.3 mm/j, en 1985. Le processus d'évaporation était responsable pour environ 85% de l'eau perdue durant cette période, avec l'autre 15% du total perdue aux écoulements de surface. De l'autre part, le debit d'eau des lacs reliés aux chenaux principaux était responsable pour 85% de la quantité d'eaux perdue, à 18.1 mm/j en moyenne. Seulement 15% de l'eau s'est égarée à l'évaporation.

Cette balance d'eau négative que subissent les lacs du delta du Mackenzie souligne l'importance de la débâcle, les embâcles de glace et la crue printanière au régime hydrologique des lacs. Donc si le débit du fleuve Mackenzie est regularisé, des modification significatives au régime hydrologique des lacs peuvent se produire, qui eux auront des conséquences graves au niveau des systemes ecologique, sociologique et économique du delta du Mackenzie.

MANAGEMENT PERSPECTIVE

The Lake Regimes, Mackenzie Delta N.W.T., study was conducted in response to proposed hydroelectric development on the Liard River. Questions were raised as to the effects river flow regulation would have on the Mackenzie Delta. A five year research period (1981-1985) was adopted to investigate the hydrological regime of these lakes. This research has contributed to a greater understanding of the processes and controlling mechanisms which affect lake water levels. Results have shown that lakes receive very little recharge from surface runoff and precipitation, and depend on spring flooding for replenishement.

As part of the federal government's committment to "Management of Northern Water Resources", the information presented in this report is essential to the development of management stratagies which will preserve the ecologic and socio-economic aspects of the Mackenzie Delta.

PERSPECTIVE DE GESTION

L'étude du régime hydrologique des lacs du delta du Mackenzie à étè conçue grâce aux questions soulever par une proposition de développement hydrolélectrique sur la rivière Liard. Quel sont les éffets potentiel de la régularisation du débit du fleuve Mackenzie sur le delta du Mackenzie?

Cette recherche, entrepris pendant cinq ans (1981-1985) a contribuée à de plus amples connaissances des processus et des mécanismes qui gouvernent le niveau d'eau des lacs. Les résultats indiquent que les lacs doivent étre innonder chaque année pendant la débâcle printanière pour se recharger car la contribution d'eau par les écoulements de surface et des précipitations ne sont pas assez pour le réapprovisionnement des lacs du delta.

Le gouvernement fédéral s'est engagé à poursuivre une politique de "gestion des resources d'eau dans le Nord", les renseignements présentés dans ce rapport sont essentiels au développement d'une stratégie de gestion qui préserverait le régime hydrologique, l'écologie et les valeurs sociales et économiques du delta du Mackenzie.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the generous support of the following individuals and organizations; special thanks and appreciation to M. Suzor, R. Smith, J. Goudie and E. Burgess (Environment Canada, Ottawa) for their assistance with field work and abstraction of data in the office; J. Ostrick and M. McRea of the Inuvik Scientific Resource Centre (Department of Indian Affairs and Northern Development, Inuvik) for their help and support with field arrangements; and Polar Continental Shelf Project (Department of Energy, Mines and Resources, Ottawa) for their generous aircraft support.

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LAKE REGIMES, MACKENZIE DELTA, N.W.T., 1985

1.0 INTRODUCTION

The Yukon and the Northwest Territories contain roughly 30 percent of Canada's fresh water (P arse et al. 1985). Because of the remoteness, harsh climatic conditions, sparse population and little industrial development, these waters remain relatively pristine. In spite of these facts, it is essential that the management strategies for northern water resources incorporate the preservation of the ecologic and socio-economic aspects of the North while the region is still in the early stages of development.

The Mackenzie River is the longest river in Canada, and flows in a northwesterly direction for approximately 1700 km, from its headwaters in Great Slave Lake to its mouth at the Beaufort Sea. The river basin drains some 1,787,000 km^2, or nearly one fifth of mainland Canada (Figure 1). Its delta, the Mackenzie Delta is recognized as an ecologically and environmentally sensitive area as it is an important staging area for waterfowl and supports a diversity of plant, fish and wildlife (Mackenzie River Basin Committee 1981). As such, the hydrodynamics of the Mackenzie River and Delta must be understood before any large-scale development in the Mackenzie River basin (e.g. hydroelectric projects) changes the flow regime.

It was in response to such proposed developments that the Mackenzie Delta Lake Regimes study was initiated in 1980. Hydrological and meteorological data were collected from 1981 to 1985 in three areas along the eastern sector of

Figure 1: Mackenzie River basin and subbasins

the Mackenzie Delta from April to September. This report highlights the analysis of data collected during the 1985 field season. The data was collected at three study areas in the Mackenzie Delta and consisted of a snow and ice survey at the end of April; aerial reconnaissance of spring break-up conditions, from late May to early June; continuous monitoring of lake and channel water levels and climatic conditions from April to September; and periodic velocity measurements from June to September.

2.0 STUDY AREA, MACKENZIE DELTA N.W.T.

The Mackenzie Delta covers an area of approximately 12,000 km^2 comprised of a maze of channels and shallow lakes which are frozen for up to eight months of the year. The Richardson Mountains to the west and the Caribou Hills to the east (Figure 2) sharply delineate the Delta. During the open water season (June to October), it is an active delta that continues to extend into the Beaufort Sea. The Delta has a very gentle slope varying only 3 to 4 metres over its 200-km length. It has numerous lakes, ponds and channels but also contains land ranging from stable forested areas in the south to tidal flats in the north. Permafrost underlies most of the Delta land mass and during the summer months, the active layer can exceed a metre or more in thickness.

The lakes and channels are underlain by taliks, extending many metres in depth (Johnston and Brown 1964). The Delta consists of three regions (Figure 2), which may be distinguished by levee height (Mackay 1963) and vegetation type (Gill 1978) (Figure 2). Levee heights decline from about 10 m a.s.l. in the southern Delta to less than 2 m a.s.l. in the northern Delta (Figure 2).

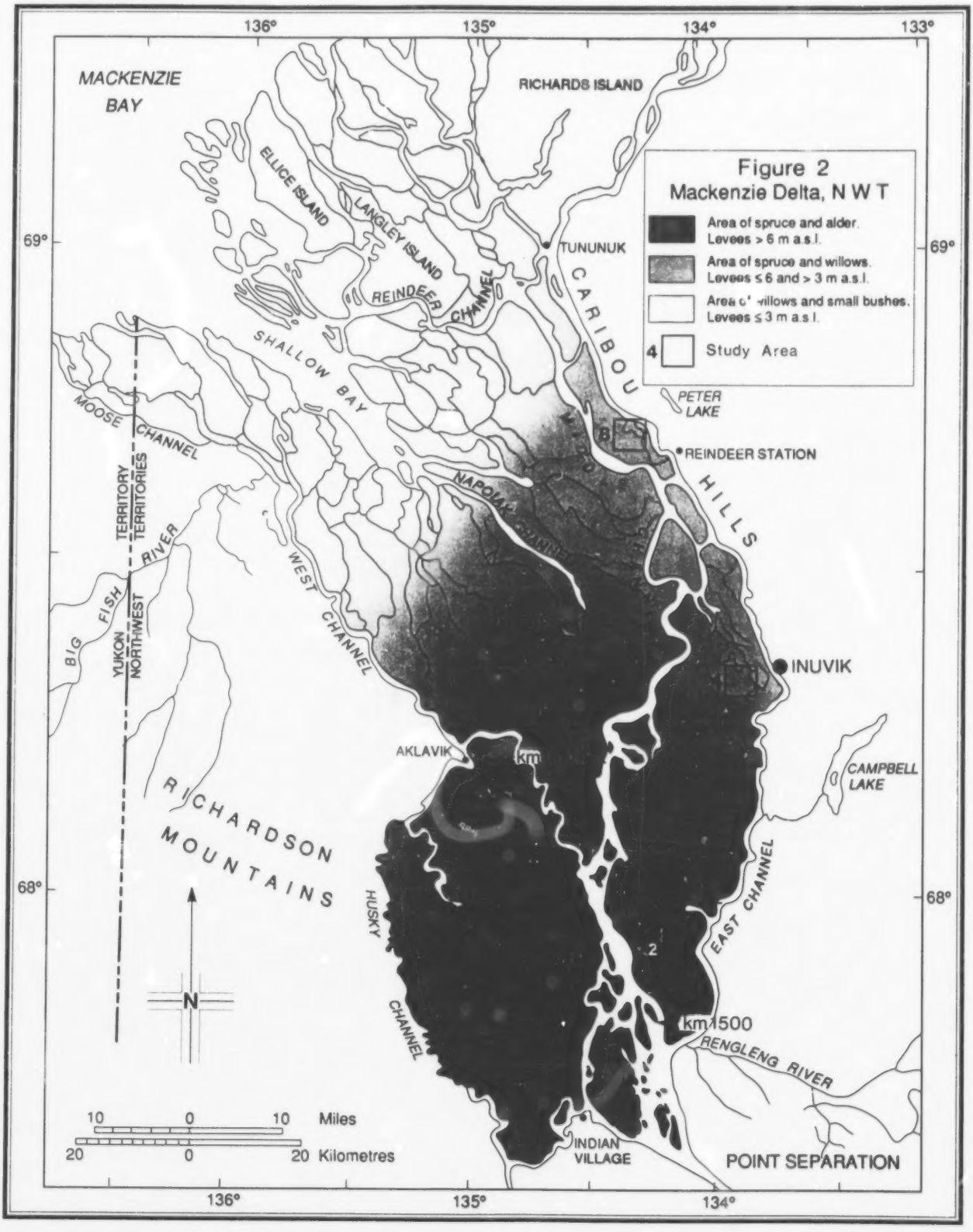


Figure 2
Mackenzie Delta, N W T
Area of spruce and alder. Levees > 6 m a.s.l.
Area of spruce and willows. Levees ≤ 6 and > 3 m a.s.l.
Area of willows and small bushes. Levees ≤ 3 m a.s.l.
Study Area
136°
135°
134°
133°
69°
68°
MACKENZIE BAY
RICHARDS ISLAND
ELLICE ISLAND
LANGLEY ISLAND
REINDEER CHANNEL
TUNUNUK
CARIBOU HILLS
PETER LAKE
REINDEER STATION
SHALLOW BAY
MOOSE CHANNEL
NAPOIAK CHANNEL
TERRITORY
TERRITORIES
YUKON
NORTH-WEST
BIG FISH RIVER
WEST CHANNEL
INUVIK
AKLAVIK
CAMPBELL LAKE
RICHARDSON MOUNTAINS
EAST CHANNEL
HUSKY CHANNEL
RENGLENG RIVER
INDIAN VILLAGE
POINT SEPARATION
N
10 0 10 Miles
20 0 20 Kilometres

The three regions in the Delta contain a diversity of lakes which fall roughly into five broad genetic types; abandoned channel lakes, point bar lakes, floodplain lakes, thermokarst lakes, and dammed lakes (Mackay 1963). Subsequent studies dealing with the hydrological regimes of lakes and channels (Bigras 1986, 1987) have categorized lakes according to their geomorphological characteristics. Connected lakes have a well defined, water-filled channel (i.e. distributary channel) connecting them to the main Delta channel system from break-up to freeze-up. These lakes are constantly interchanging water with Delta channels, and the lake level is similar to the distributary channel level throughout the open water period (May to October). Connected lakes are located throughout the Delta and have an average depth of 1.30 m in mid-summer (Bigras 1987).

Most lakes not directly connected by a channel in the Delta are perched atop levees and are cut off from other lakes and channels for most of the year. These perched lakes have an average mid-summer depth of 1.0 m (Bigras 1987). Perched lakes can be divided into three groups. The first two groups are made up of perched lakes located in the northern and central Delta, and have a small depression in the levee hidden by overgrowth, linking them to other lake systems. These lakes are known as lakes with closures (Mackay 1963). They can have either a high- or low-closure connecting them intermittently to other lakes or channels during the brief spring flood or occasionally during high water in the summer. When water levels increase sufficiently, 2.0 metres a.s.l. or less for low-closure lakes, and 2.0 metres a.s.l. or more for high-closure lakes infilling commences (Bigras 1985). The third group consists of unconnected lakes which are elevated high above the Delta channel system, have no depression in the levee linking them to another lake system, and are not

flooded annually. These lakes are located exclusively in the southern portion of the Delta and tend to have a negative annual water balance.

One representative study area was chosen from each of the three Delta regions. Each was to include a distributary channel linking a connected lake to the main Delta channel system, as well as one other lake from the remaining two categories. Study areas were located along the eastern sector of the Delta because of their accessibility (Figure 2).

Area 2 (67° 56'N ; 134° 07'W), approximately 50 km southwest of Inuvik, has an average levee height of 10 m a.s.l. It is situated in a region where shallow lakes cover approximately 20% (*) of the area.

The study area consists of three study sites, an unconnected lake, a high-closure lake and a distributary channel (Insert, Figure 3). The distributary channel is more than 5 km in length and links several lakes, varying in size from 0.004 km^2 to 2.5 km^2 in mid-summer. The high-closure lake is located 1.1 km up-stream of the distributary and secondary channel confluence. Over this distance, the channel has a slope of 4.5×10^{-3}. The high-closure lake is 460 m and varies in width from 30 m to 130 m. It has an area of 0.05 km^2, a maximum depth of 1.60 m, and an average mid-summer depth of 1.15 m. The unconnected or

---

(*) Percentage figures for lakes occupying an area were obtained through air photo analysis. Three swaths approximately 10 km wide and extending across the southern, central and northern Delta were overflown a minimum of three times each as part of the Delta break-up study. Lake, channel and landmass areas within each swath were measured using a digital planimeter.

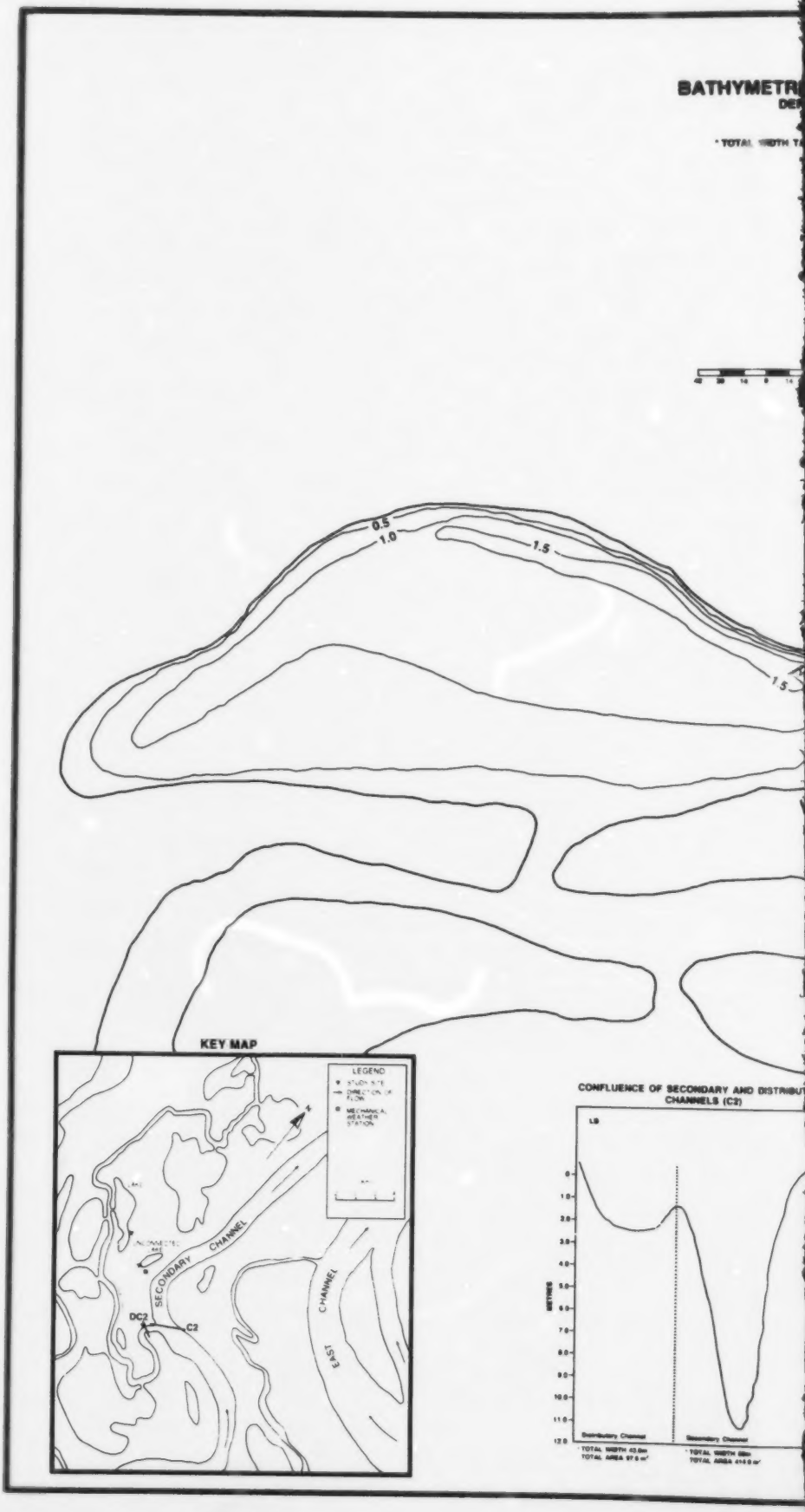
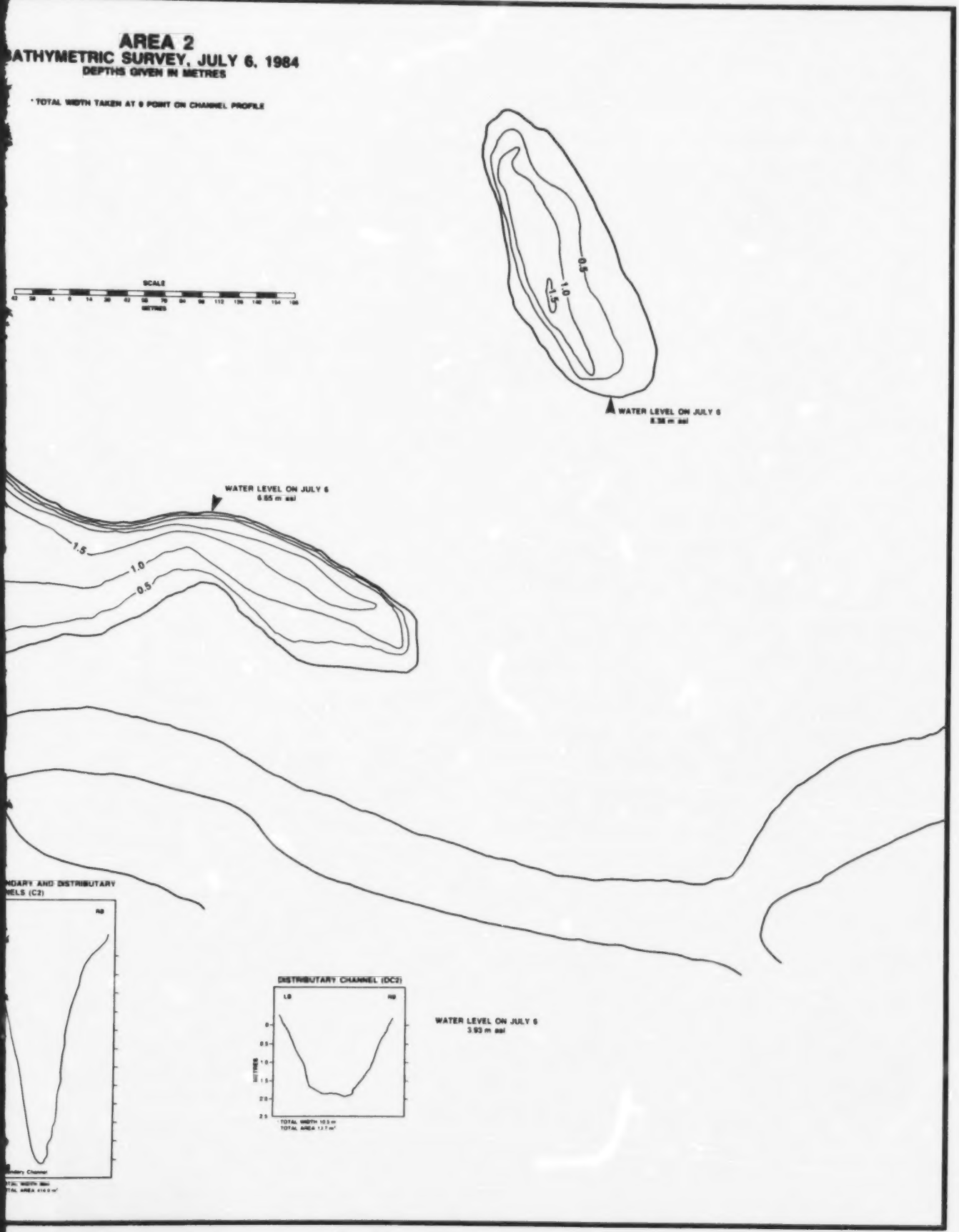

BATHYMETR
0.5
1.0
1.5
1.5
KEY MAP
LEGEND
SECONDARY CHANNEL
EAST CHANNEL
DC2
C2
CONFLUENCE OF SECONDARY AND DISTRIBU
CHANNELS (C2)
LS
METRES
Distributary Channel
Secondary Channel

FIGURE 3

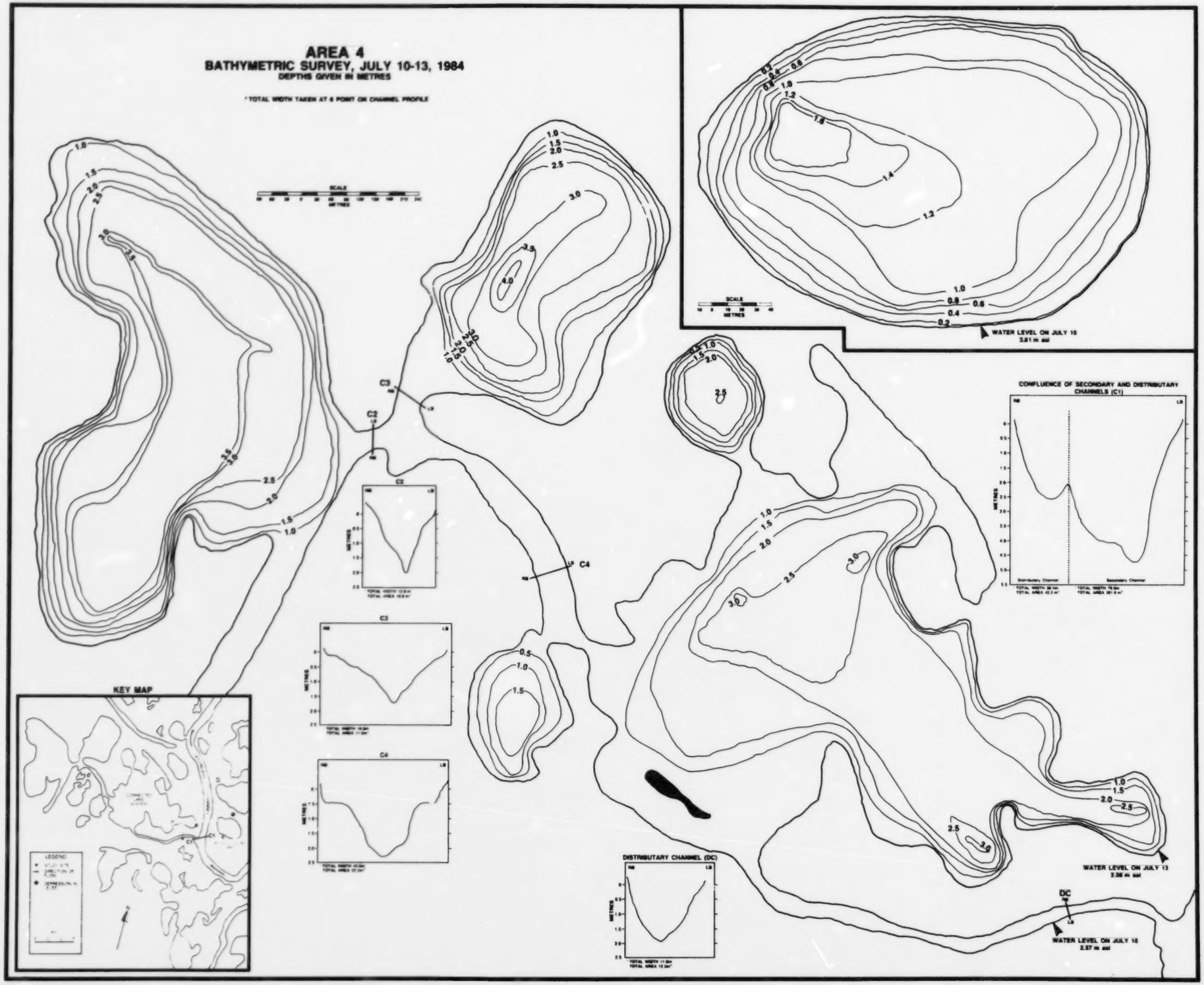

AREA 2
ATHYMETRIC SURVEY, JULY 6, 1984
DEPTHS GIVEN IN METRES
* TOTAL WIDTH TAKEN AT 0 POINT ON CHANNEL PROFILE
SCALE
METRES
0.5
1.0
1.5
WATER LEVEL ON JULY 6
8.38 m asl
WATER LEVEL ON JULY 6
6.85 m asl
1.5
1.0
0.5
NDARY AND DISTRIBUTARY
NELS (C2)
RB
DISTRIBUTARY CHANNEL (DC2)
LB
RB
METRES
WATER LEVEL ON JULY 6
3.93 m asl

Perched lake has an area of 0.006 km^2. As of the spring of 1985, it was 150 m long, 40 m wide, has a maximum depth of 1.40 m, and in mid-summer an average depth of 0.60 m.

Area 4 (68° 19'N ; 133° 46'W), approximately 6 km southwest of Inuvik has an average levee height of 5.5 m a.s.l. (Figure 2). In the central region the lakes cover about 40% of the area. The study area includes a high-closure lake, a distributary channel and a connected lake system (Insert, Figure 4). The channel is 0.02 km long, has an average slope of 7.0×10^{-4} and leads directly into a series of connected lakes. Short channels link the lakes creating a combined water area of 1.33 km^2. The principal lake under investigation has an area of 0.51 km^2, is 800 m long, varies in width from 275 m to 700 m, has a maximum depth of 3.00 m and an average mid-summer depth of 1.70 m. The high-closure lake extends over an area of 0.065 km^2. It is intermittently linked to a connected lake system by flow through a depression in the northeast portion of the levee (Insert, Figure 4). The lake has a high sill level at approximately 3.80 m a.s.l. It has an average depth of 0.90 m with a maximum depth of 1.60 m, and is about 300 m long and 200 m wide.

Area 8 is in the northeastern sector of the Mackenzie Delta (68° 43'N ; 134° 15'W), 50 km northwest of Inuvik (Figure 2). The average levee height is 4.5 m a.s.l.. Area 8 is also in the central portion of the Delta, but lakes in this region occupy approximately 50 % of the area. The study area is adjacent to the northern Delta region where the area occupied by lakes varies depending on the time of the year and the water level. In mid-summer lakes usually occupy 25% of the region.

FIGURE 4


AREA 4
BATHYMETRIC SURVEY, JULY 10-13, 1984
DEPTHS GIVEN IN METRES
* TOTAL WIDTH TAKEN AT 6 POINT ON CHANNEL PROFILE
SCALE
METRES
WATER LEVEL ON JULY 10
3.61 m asl
CONFLUENCE OF SECONDARY AND DISTRIBUTARY CHANNELS (C1)
RB
LB
METRES
Distributary Channel
Secondary Channel
C2
C3
C4
DC
DISTRIBUTARY CHANNEL (DC)
KEY MAP
LEGEND
WATER LEVEL ON JULY 13
2.98 m asl
WATER LEVEL ON JULY 10
2.57 m asl

Area 8 contains a distributary channel, a connected lake system and a low-closure lake (Insert, Figure 5). The distributary channel, which connects the lake system to the secondary Delta channel, is 0.85 km long with a gradient of 1.0×10^{-4}. The connected lake system comprises three lakes and covers an area of 1.58 km^2. The principal lake under investigation (0.60 km^2), is 900 m long, varies in width between 150 m to 750 m, and has an average mid-summer depth of 1.15 m and a maximum depth of 2.25 m. The low-closure lake covers an area of 0.026 km^2. A depression in the levee is located in the northeast corner of the lake, and has an elevation of 1.72 m a.s.l. (Insert, Figure 5). The lake has an average mid-summer depth of 1.10 m with a maximum depth of 1.65 m.

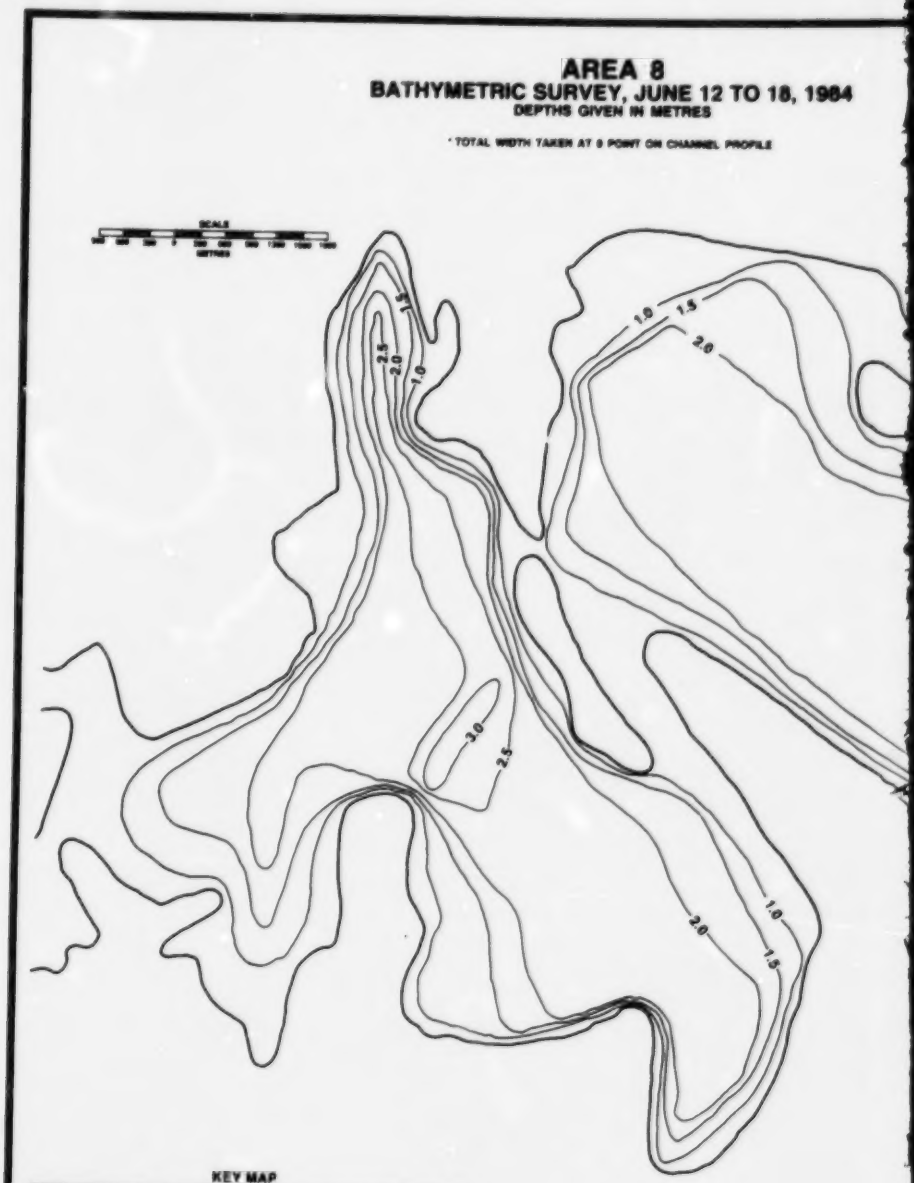
2.1 METHODOLOGY

In the early sixties, work on the hydrological regime of the Mackenzie River and Delta showed that peak water levels occur during the spring break-up period (Mackay 1963, and MacKay 1965). Yet until recently (Bigras 1985, 1986), attempts to obtain a continuous record of water levels during break-up using conventional techniques (i.e. stilling well and bubbler system) had been continually frustrated by the destructive force of ice shove and scour along river and channel banks.

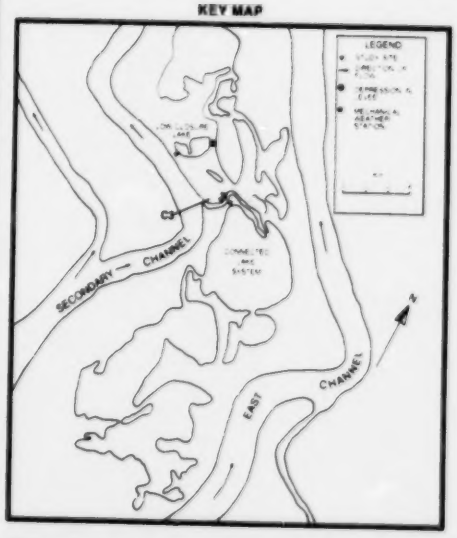
Prior to break-up in late April, time-lapse camera systems were set in place. The 16 mm time-lapse camera system, used to monitor water levels, was designed and developed by J. Banner and R.O. van Everdingen, (1979). Each of the nine camera systems was focussed on a series of one metre staffs, arranged along the lake edge or up the channel slope. All staffs were surveyed and tied

AREA 8
BATHYMETRIC SURVEY, JUNE 12 TO 18, 1984
DEPTHS GIVEN IN METRES

* TOTAL WIDTH TAKEN AT 0 POINT ON CHANNEL PROFILE



KEY MAP



CONFLUENCE OF SECONDARY AND DISTRIBUTARY CHANNELS (C3)

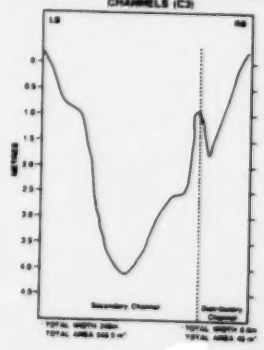
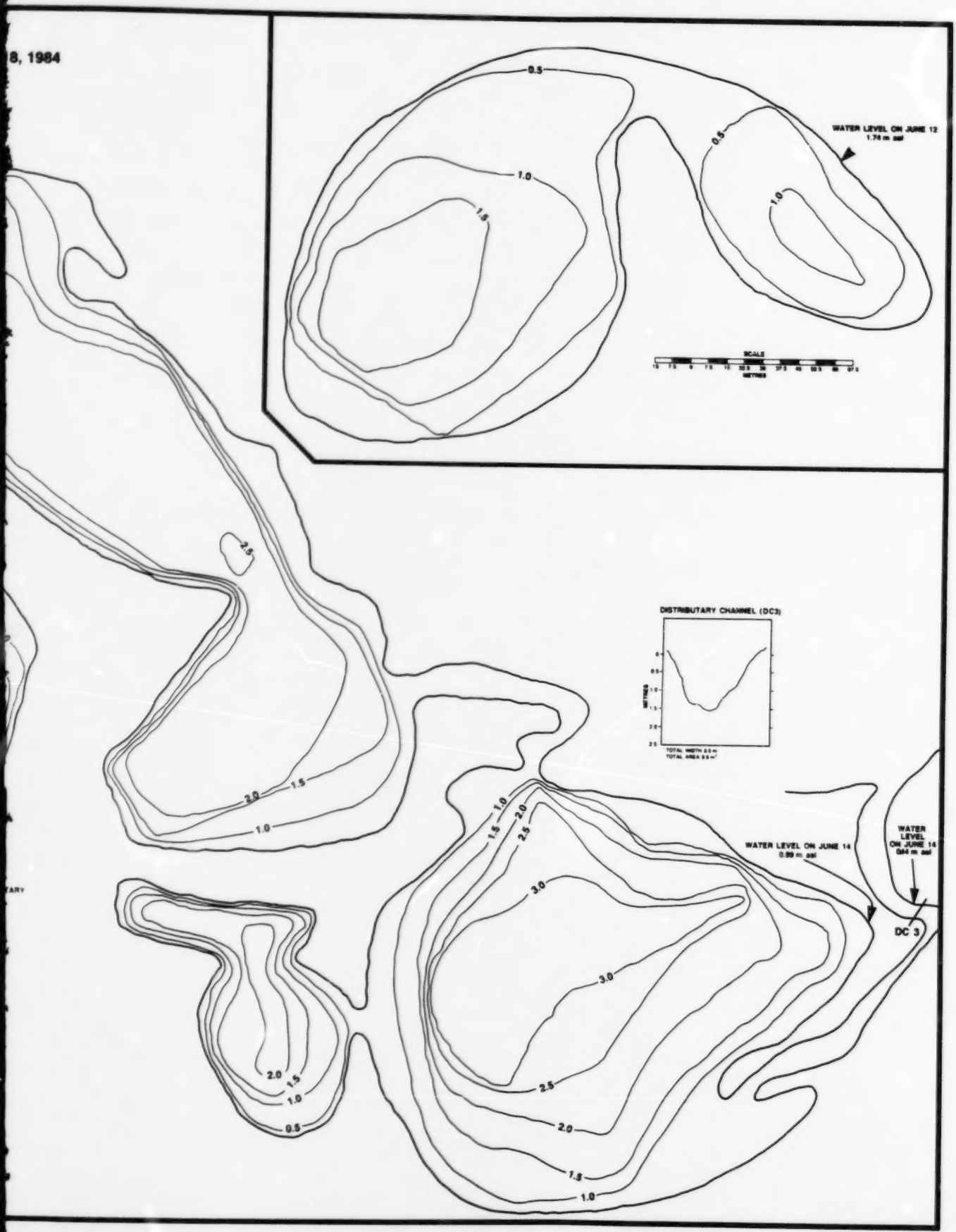


FIGURE 5


8, 1984
0.5
1.0
1.5
WATER LEVEL ON JUNE 12
1.74 m asl
SCALE
METRES
2.5
DISTRIBUTARY CHANNEL (DC3)
METRES
2.0
1.5
1.0
WATER LEVEL ON JUNE 14
0.59 m asl
WATER LEVEL ON JUNE 14
0.64 m asl
3.0
DC 3

into a common datum to allow the relative water levels between the lakes and the channels to be inter-related. Readability of water level on these staffs varies from ±1 mm on staffs directly in front of the camera system to ±2 cm on staffs located 10 metres or more away from the camera system.

Cameras were pre-set to take photographs every three hours and were capable of recording for up to 90 days without interruption, so that only one camera change per system was required mid-way through the field season.

In conjunction with 16 mm water level photography, hourly air temperatures, precipitation, wind velocity and direction were recorded throughout the field season at Areas 2 and 8. Climatic data from the AES station at the Inuvik Airport was used for Area 4 because of its proximity (Figure 2). Prior to break-up, field measurements of snow-pack water equivalents, and lake and channel ice thicknesses were undertaken.

Break-up was monitored using aerial photography to obtain information on the timing, progression, locations, dimensions of ice jams and on the extent of backwater flooding. Supplemental information was acquired from 35 mm hand-held oblique photography and videos, during fixed-wing and helicopter flights.

Lake morphometry was obtained through a detailed bathymetric survey conducted at each lake site during the summer of 1984. Lake volumes were then calculated using a simple volume equation V = A(area) x D(depth).

As soon as channel conditions permitted (i.e. clear of ice), velocity measurements were made at the three distributary channel sites once every two

weeks, weather conditions permitting. Discharge was then calculated using Q = A(area) x V(velocity). A continuous velocity record was obtained using a modified RCM 4/5 Aanderaa recording current meter.

3.0 DATA ANALYSIS and DISCUSSION

3.1 SNOW SAMPLING SURVEY

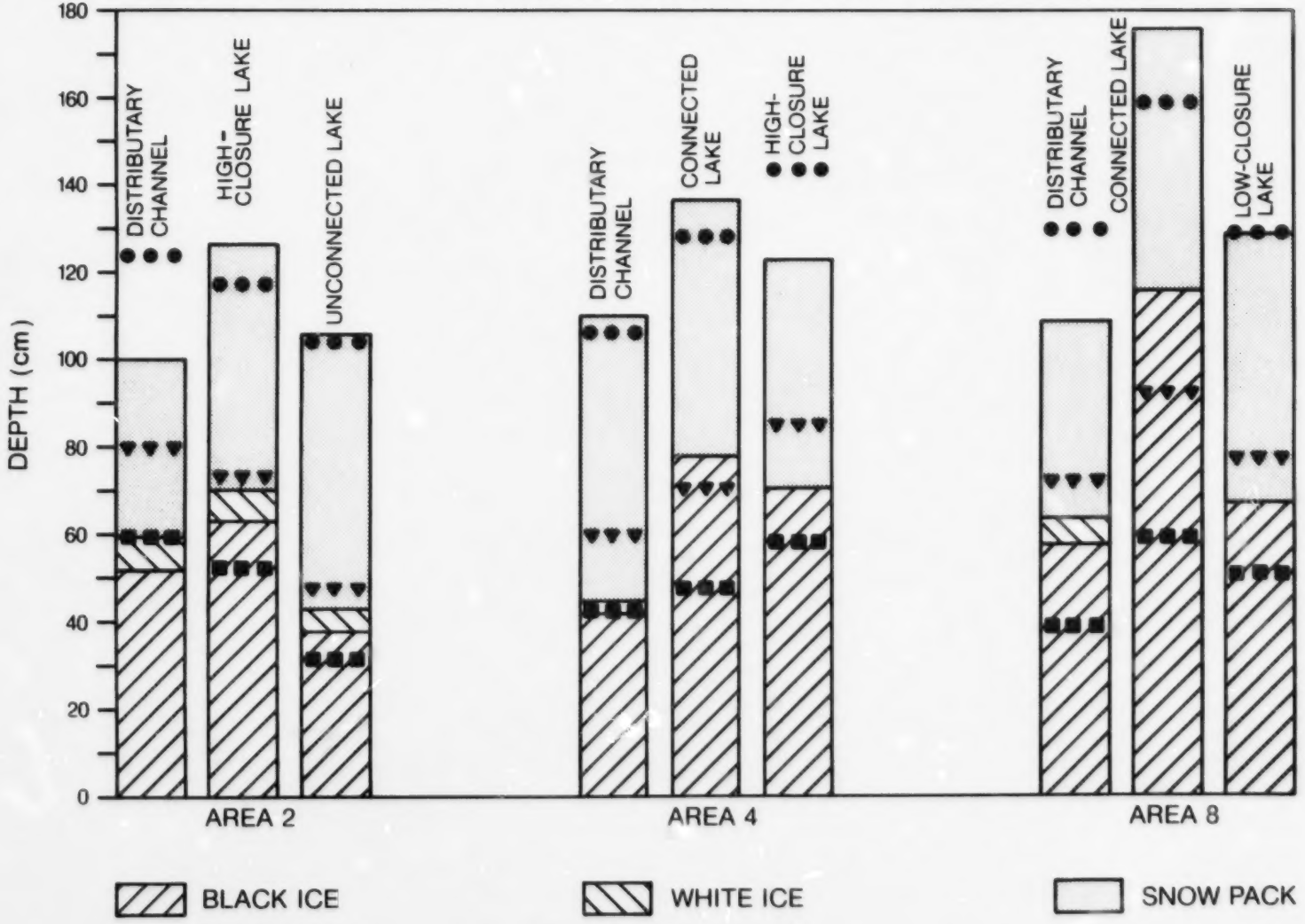
Snow surveys were conducted toward the end of April at all three study areas. Mean snow-pack depths for each of the nine study sites are plotted against average snow depths for 1985 in figure 6.

In comparison with previous years (1980-1984), the average spring snow-pack depth for 1985 was normal. The average water equivalent was 30.4 cm, with a standard deviation of 3.8 cm among the areas. The 1985 water equivalent was 10.1 cm above the five year mean of 20.3 cm. Given a 100% increase in water equivalent for the year, an increased contribution from snow-melt run-off to the surrounding lakes is not unexpected, and is in fact needed to sustain unconnected and high-closure lakes in the southern region of the Delta, as they have a negative annual water balance, and are not flooded annually during spring break-up (Bigras 1986; Marsh and Bigras 1988a).

3.2 ICE THICKNESS SURVEY

Ice thicknesses were also measured early in the spring when maximum ice thickness was expected. A series of holes were drilled in order to obtain an accurate ice profile, the average was then taken as the representative ice thickness for each study site (Figure 6). The average ice thickness in 1985

FIGURE 6: AVERAGE ICE THICKNESS AND SNOW DEPTH, MACKENZIE DELTA, 1985



MEAN ICE THICKNESS AND SNOW DEPTH (1981-85)

■ BLACK ICE ▼ WHITE ICE ● SNOW PACK

for Delta lakes and channels was 74 cm and 57 cm respectively. Ice thicknesses varied by as much as 50 cm among the study sites (Figure 6), but the average ice thickness for 1985 was 68 cm, only 2 cm above the five year mean of 66 cm.

One particular characteristic of the ice composition was the thickness of the white ice which had a range of zero to eight centimeters. This was far below the 5-year mean of 17 cm, an indication there was very little snow-melt run-off, or water was being forced up onto the ice cover and refreezing during the winter. The black ice component had an average thickness of 65 cm, approximately 20 cm above the 5-year mean, an indication that very cold air temperatures with very little snow cover dominated early on during the winter.

3.3 SPRING BREAK-UP

The mean date for complete freeze over of East Channel at the town site of Inuvik is October 11 (Allen 1977). Over the winter, channel water levels can drop a metre or more below the autumn low-water level, causing the ice cover to sag and hinge cracks to appear. This effectively isolates distributary channels in the southern portion of the Delta from flow in the main Delta channels. In the spring as shore leads develop and water levels rise in the main channels, the height difference incurred over the winter, exhibited by the sagging ice cover, must be matched before any increase in the distributary channel water level will occur. On the other hand, channels and lakes located in the central and northern Delta are not as elevated, and are cut off from the main Delta channels because they are frozen solid, or have an elevated lake closure. This difference in levee height from south to north also affects the initial

sequence in which lakes located in the three Delta region are flooded during spring break-up.

The transition from winter to spring is an abrupt one in the Delta. Climatic data obtained from the AES station in Inuvik (Environment Canada 1985) showed an increase of approximately 20.0°C in the mean monthly temperature recorded between April-May and 10.0°C between May-June (Figure 7). The mean monthly air temperatures for April 1985 was 9.4°C colder than the 23-year mean monthly normal of -9.8°C. Both May and June exceeded their mean monthly normals by 0.9°C (Environment Canada 1986). Each day in April received on average 8.6 hours of sunshine, while May averaged only 8.2 hours per day. The prevailing winds direction was from the east northeast, and the total precipitation was light for April and May at 11.1 mm and 27.2 mm respectively.

Warm air temperatures, increased solar radiation, and snow-melt run-off caused shore leads to appear alono Delta channels as early as May 1. Large shore leads at the ice bridge crossing on the Mackenzie River at Arctic Red River made crossing unsafe, and prompted officials to close it on May 9. The ice road at Inuvik was closed several days earlier on May 1, as result of shore lead development and water ponding on the ice surface. Even so, the ice cover was still quite competent.

The ice cover started to move on the Mackenzie River at the confluence with Arctic Red River on May 22. Vast amounts of brash ice intermixed with ice flows continuously entered the Delta. The ice cover down-stream of the settlement of Arctic Red River was broken by a low velocity spring flood wave entering the Delta (Bigras 1988). The advancing ice front stalled as it abutted the

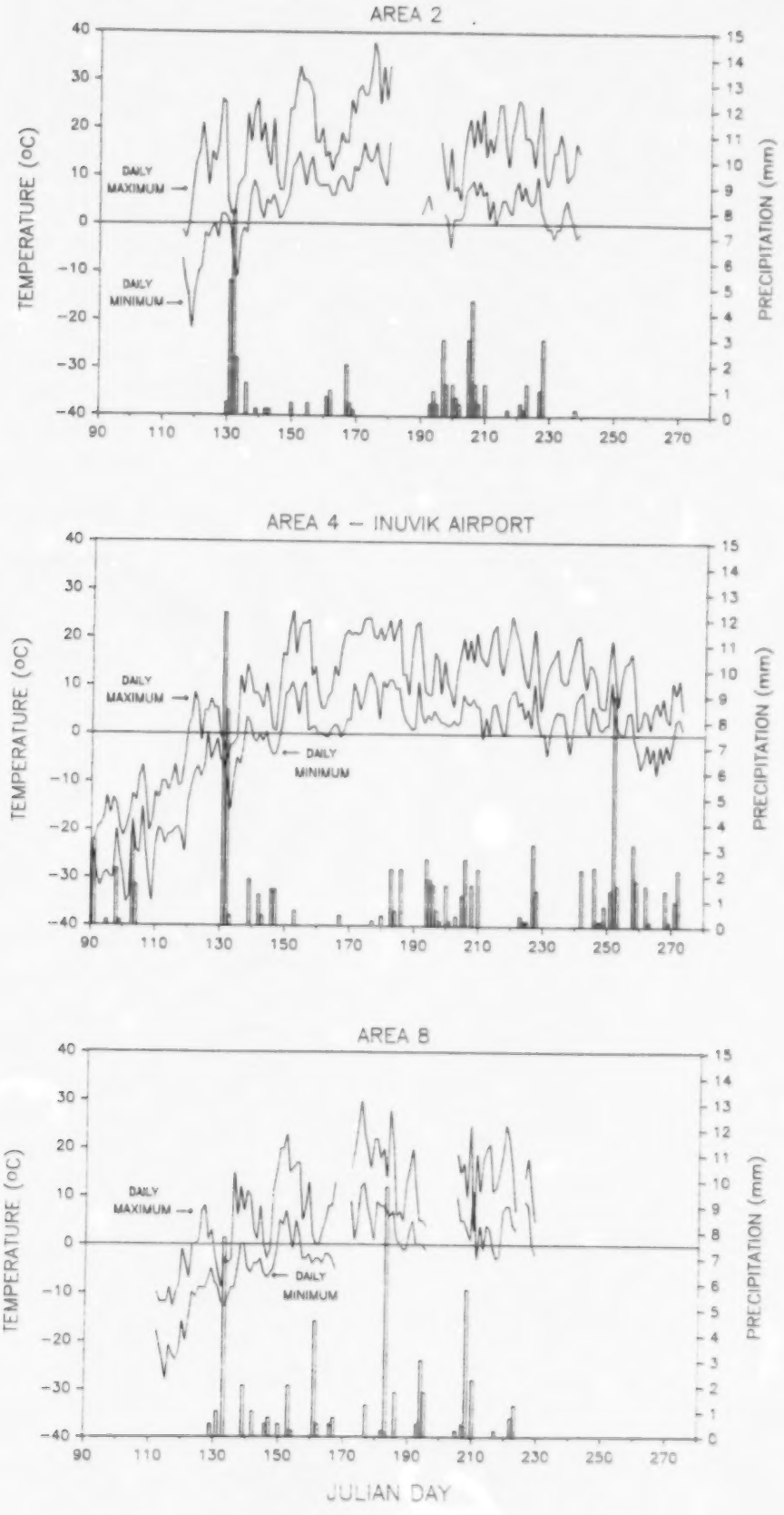


Figure 7 : Daily meteorological observations, 1985.

fractured ice cover just down-stream of a large group of islands, at km 1450 (Figure 2). By May 27, backwater flooding had reached a peak of 16.95 m a.s.l. at the confluence of the Mackenzie and Arctic Red rivers (Bigras 1988). The head of the ice jam was located around km 1453, and extended as far down-stream as km 1500. The jam covered an area of 168 km^2, and remained static until June 1 when it failed. On June 1, the area occupied by the ice jam had decreased considerably to 133 km^2, as a result of lower albedo, warmer water, longer periods of sunshine and higher air temperatures. Once the jam had failed, the ice front advanced freely downstream until it ran into the next cluster of islands on Middle Channel (km 1530), at which point the ice began to jam up again.

The average daily air temperature from May 27 to June 1 was 8.7°C, 3.0°C above the mean daily norm for this time of year. Daily sunshine hours averaged 13, and there was only one day of precipitation totalling 1.4 mm. The prevailing wind direction was east-northeast. There were only traces of the snow cover by May 27, all of which had melted away by June 1.

The average daily air temperatures recorded in the southern and northern Delta study areas for this period varied a great deal. Both study areas are consistently located on either side of mean daily air temperature isotherms as defined by Burns (1973). Both study areas are under the influence of different climatic controls, and during spring break-up these factors are compounded by localized ice conditions and the progress of the advancing ice front. In the southern Delta the daily average for May 27 to June 1 was 15.3°C, while at the northern site it was only 0.6°C.

With the ice jammed in Middle Channel, the spring flood wave is forced through smaller secondary and distributary channels before reaching connected lakes and/or lake systems. Under these conditions the normal flow direction of distributary channels is reversed. These floodwaters are heavily sediment laden, and when the inflowing current meets the lake water sediment is deposited, forming a small reverse delta (Mackay 1963) in many of the connected lakes.

Backwater levels from ice jamming in the southern portion of the Delta did not increase sufficiently to overtop levees and flood the many elevated lakes (Figure 2). The contribution of snow-melt run-off from surrounding lake catchments to the lakes was minimal. Infiltration and evaporation curb the contribution that snow-melt run-off will have on lake water levels. On average only 13% of the total available run-off from snow-melt in a Delta lake catchment will enter a lake as surface flow (Bigras 1986).
In 1985, only 5% of the total available run-off from snow-melt contributed to the increase in lake water level.

Disributary channels are the first to experience an increase in water level as a result of spring flooding, with the central and northern Delta sites responding several days ahead of the southern site. The first substantial increase in water level was recorded on May 12 and 13 at the distributary channel sites in Areas 4 and 8 respectively. The first noticeable rise in the water level of the distributary channel in Area 2 was on May 17. By June 1 it had reached a peak level of 8.74 m a.s.l., 5.86 metres above its initial spring level (Table 1; Figure 8a). Of the two lakes under investigation in Area 2, the high-closure lake was the only one flooded (Figure 9a). Due to a failure of the

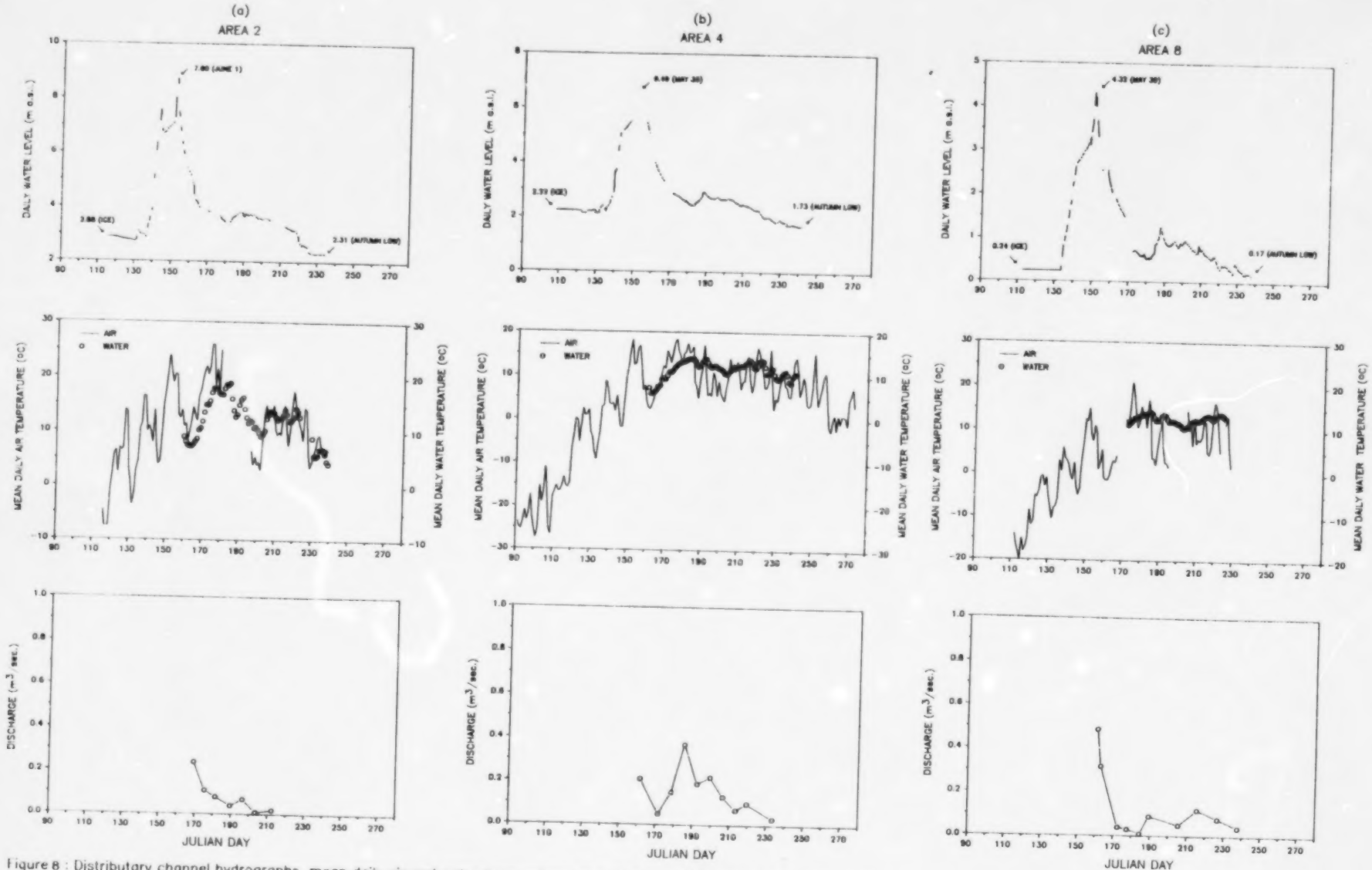


Figure 8 : Distributary channel hydrographs, mean daily air and water temperature, and discharge, Mackenzie Delta, NWT, 1985.

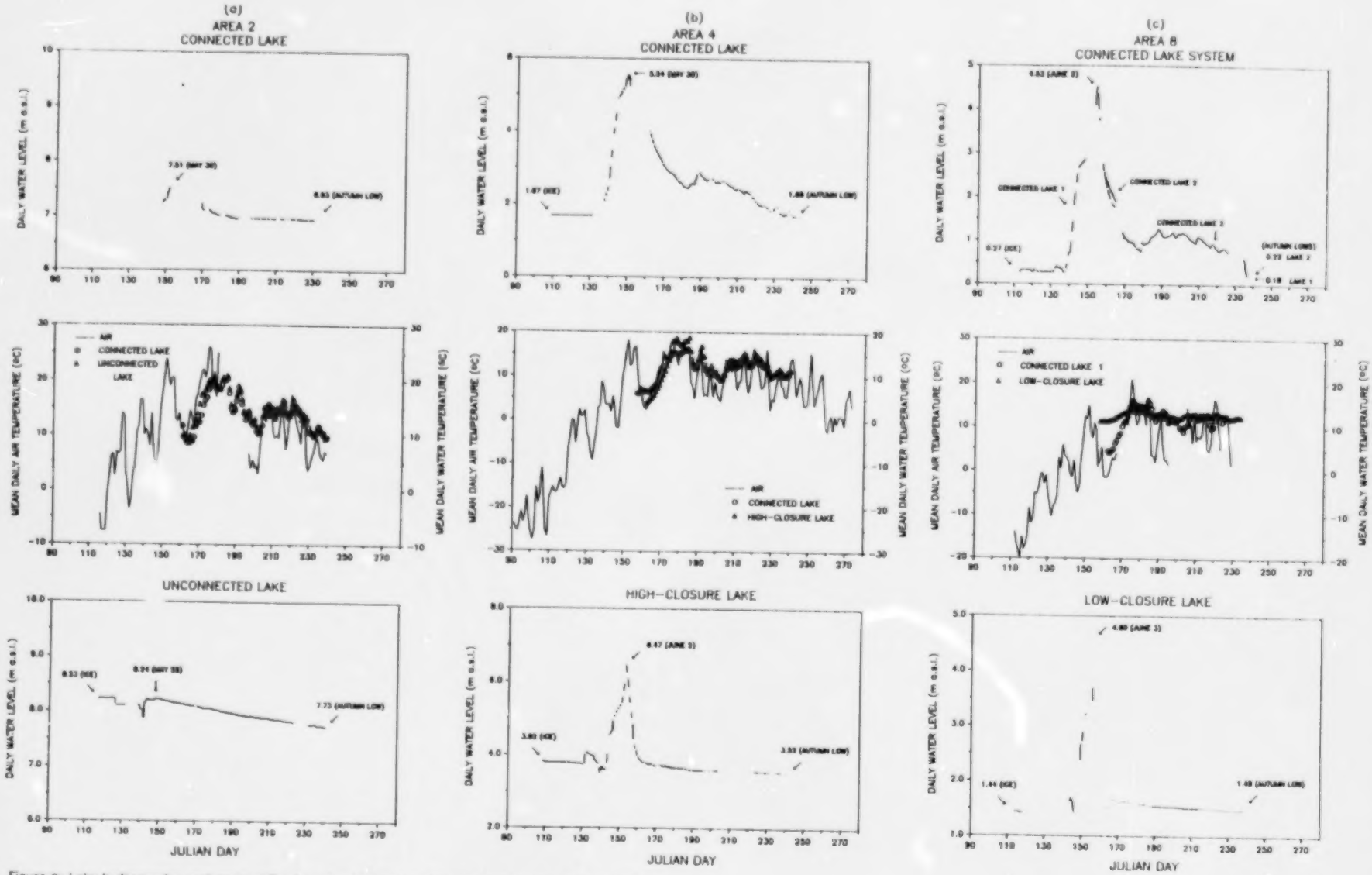


Figure 9: Lake hydrographs, and mean daily air and water temperature, Mackenzie Delta, N.W.T., 1985.

camera system, a complete water level record for the high-closure lake site during break-up was not obtained. On May 31, a peak of 7.51 m a.s.l. was recorded, which translates to an over all increase in the water volume of 74% over its average mid-summer volume (Table 2). The unconnected lake water level fluctuated throughout the spring break-up period, but not as a result of spring flooding. Water lost through infiltration and evaporation resulted in a decrease in the lake water level. The expected increase in lake level from snow-melt run-off as a result of the above-normal snow-water equivalent did not materialize. A peak of 8.24 m a.s.l. was recorded on May 28, only 10 mm above its spring ice level of 8.23 m a.s.l. (Figure 9a). At its maximum level, the unconnected lake water volume was 15% less than its mid-summer volume recorded in 1984 (Table 2).

Farther down-stream in the central region, levees and lake closure elevations are much lower than those of the southern Delta. Consequently, the spring flood wave inundated many of the lakes and channels in this region first. The water level at the distributary channel in Area 4 started to rise on May 12. It peaked on May 30 at 6.49 m a.s.l., 4.27 metres above its spring ice level (Figure 8b).

Water also started pouring into the connected lake on May 17, until it finally peaked on May 30 at 5.54 m a.s.l., 3.87 metres above its spring ice level of 1.67 m a.s.l. (Table 1: Figure 8c). The corresponding increase in the lake water volume was 204% above its average mid-summer lake volume (Table 2). The high-closure lake reached its peak on June 2 when it rose to 6.47 m a.s.l., 2.65 m above its spring ice level. This represents a 279% increase above its average mid-summer volume (Table 2).

The northern Delta was flooded completely during the spring break-up period. The distributary channel in Area 8 showed the first signs of flooding on May 13. It reached its peak of 4.32 m a.s.l. on May 30. This was a rise of 4.08 metres above its spring ice level (Figure 8c). The connected lake increased by 4.26 m above its spring ice level (Table 1; Figure 9c). Its peak of 4.53 m a.s.l. on June 2 increased the lake volume by 334% over its average mid-summer volume (Table 3). The low-closure lake peaked on June 3 at 4.60 m a.s.l., 3.16 m above its spring ice level (Table 1; Figure 9c), and 260% above its average mid-summer lake volume.

3.4 POST BREAK-UP

For the purpose of clearity, the post break-up period in this report is defined as that period which begins once the ice front has reached the Beaufort Sea. Lakes and channels customarily experience a rapid decline in water level as the flood wave surges downstream.

Air temperatures continued their above normal trend, causing lake ice to deteriorate throughout the Delta. All major channels were open with water running freely down-stream. In fact, by June 4 the advancing ice front had cleared the Delta. There was still some ice running in channels, and some brash ice was stranded along channel banks where ice jams had formed.

The mean daily air temperature at the Inuvik Airport from June 4 to 22 was 9.1°C, with a daily sunshine hour average of 13.8. The prevailing wind direction was east-northeast, and the total amount of precipitation was 0.4 mm. The mean daily air temperature recorded at the southern site was 13.1°C, and 3.9°C for the northern site (Figure 7). The prevailing wind direction, however,

for the northern site was northeast.

Lakes and channels customarily experience a rapid decline in water level once an ice jam fails, and the accompanying floodwaters surge down-stream. Once backwater flooding has ceased, the normal flow direction is re-established in the distributary channels.

On June 1, the ice jam located on Middle Channel around Area 2 failed. The distributary channel water level dropped sharply, 1.79 m in 48 hours (Figure 8a). Over the next 11 days (June 4 to 14) it dropped another 2.87 m (Figure 8a). The recession portion of the hydrograph for the high-closure lake (Area 2) is incomplete, but the remaining segment shows there was some surface outflow from the lake to the distributary channel. There was a decrease in the lake level measured on May 30 and June 18 of 0.28 m. This represents a 14% decrease in the lake volume recorded on May 30, 95% of which was outflow. This outflow accounted for 5% of the total discharge measured further down-stream at the mouth of the channel site. During the same period (May 31 to June 18), the mean daily water temperature was 9.0°C, and rising (Figure 9a). The unconnected lake in the area was not flooded (Figure 9a). From May 28 to June 22, the lake level decreased by 0.68 mm/d, mostly as a result of infiltration. The mean daily water temperature for the same period was 16.2°C (Figure 9a).

As of June 20, the distributary channel (Area 4) water level had dropped 3.60 metres from May 31 to June 23 at an average rate of 163 mm/d (Figure 8b). The decrease in the water level was accompanied by a rise in the average daily water temperature, 7.7°C from June 10 to 20.

The connected lake level fell 2.58 metres, at a rate of 110 mm/d, from May 30 to June 10. Its spring peak volume was reduced by 30% (3.71 $x10^6 m^3$), over 90% of which was lost through surface outflow. The lake water temperature was rising, with a daily average of 8.3°C (Figure 9b). Upon the release of a small ice jam on Middle Channel (June 2), the high-closure lake level decreased by 1.45 metres, at an average rate of 480 mm/d from June 2 to 5 (Figure 9b). The lake level decreased by another 1.23 metres, from June 6 to 11, accounting for a 70% decrease in the lake volume when compared to its spring maximum (Table 2). Ninety-nine percent of this water was lost through surface flow running out of the high-closure lake towards a lower lake system via a small connecting channel at the southeast end of the lake (Insert, Figure 4). The water level in the lake fell below the closure elevation of 3.81 m a.s.l. on June 11, cutting off any further outflow. The lake water temperature for the same period had an average daily temperature of 6.4°C and was increasing (Figure 9b).

Lake and channel water levels in Area 8 were also affected by ice jam failure and surging floodwaters. The distributary channel water level fell 1.76 metres from May 30 to June 4 at a rate of 350 mm/d. The connected lake level decreased by 1.77 m in three days, June 2 to 5 (Figure 8c). It lost 4.56 $x10^6$ m^3, 64% of its peak spring volume (Table 2), at a rate of 590 mm/d. By June 10, the water level of the low-closure lake had gone down by 2.88 metres (Figure 9c), at a rate of 360 mm/d. This represents a decrease in the peak lake volume of 27%, for a total of 27468 m^3 (Table 2). Surface flow out of the lake through a small channel connection at the northeast end of the lake to the lower adjacent lake system (Insert; Figure 5) also ceased on June 10. The water level was even with the lake closure level of 1.72 m a.s.l. Water temperatures were not recorded at lake site in Area 8 until June 11.

3.5 OPEN WATER PERIOD

Once spring floodwaters subside, connected lakes begin to empty via their distributary channels, resuming the normal direction of flow (e.g. water flows from the lakes to the channels). Flow reversal does occur on occasion during the open water season if the channels have a low water connection to other Delta channels (i.e. central and northern Delta channels), and hydrometeorological conditions are favorable.

Distributary channels and lakes in the southern, central and northern Delta do not respond to hydrometeorologic conditions in a similar manner. In the central and northern regions of the Delta, there is a continuous exchange of water between the connected lakes and their distributary channels. Since most of the channels in these regions have low level connections to main Delta channels, hydrometeorological events originating further up-stream (i.e. Mackenzie River basin) often register at these sites, and in some instances have caused flow reversal in the distributary channels. Channels in the northern Delta are also susceptible to tidal fluctuations and to storm surges which can cause flow reversal (Henry 1975; Bigras 1985). Because of their elevation, lakes in the southern region have not experienced a flow reversal during the course of this study.

Variations in summer water levels of "perched" lakes or lakes with closures are small when compared to those occurring during spring break-up (Figure 9). To a lesser extent the same observation applies to connected lakes (Figure 9). The suspended sediment load brought into the lakes by the spring floodwaters begins to settle out in the lakes. Small delta formations known as reverse

deltas (Mackay 1963) become visible at the lake-channel interface.

The mean daily air temperature during the open water period (June 23 to August 31) at the AES station in Inuvik was 10.7°C, only 0.2°C above the mean daily norm of 10.5°C (Environment Canada 1986). On average there were 10.5 hours of sunshine each day, normal for this time of year. Total precipitation in the area was 29.8 mm, much less than the norm of 93 mm for this period (Environment Canada 1982). The prevailing wind direction was north by northwest. Area 8 had a mean daily air temperature of 9.7°C from June 23 to August 17, and 29.5 mm of precipitation. In Area 2 the mean daily air temperature from June 23 to August 27 was 11.3°C, and the total precipitation was 25.7 mm. The prevailing wind direction was northwest for both of these study Areas.

On seven occasions from June 18 to July 31 discharge was measured at the distributary channel site, Area 2 (Insert, Figure 3). By this time, discharge had decreased drastically from the highs associated with the spring flood. The vast majority of lakes in the southern Delta are perched, and as such, the water level usually drops below the closure elevation by mid-summer, at which time they cease to feed their respective distributary channels. This phenomenon is reflected in the amount of discharge, which inevitably decreased as the season progressed (Figure 8a). The average discharge was 0.08 m^3/sec, with a high of 0.24 m^3/sec and a low of 0.01 m^3/sec. The channel is very shallow late in the summer (0.25 to 0.50 metres), and had an average daily water temperature of 12.4°C. Generally the average daily water temperature was only a few tenth of a degree less then the average daily air temperature (Figure 8a).

A continuous record of the water level, velocity and water temperature at the secondary channel in Area 2 (Insert; Figure 3) was also collected from June 09 to August 12. The data is presented in figure 10, and illustrates the influence meteorologic conditions have on the hydrologic regime of a typical secondary Delta channel.

A distinctive feature of the channel hydrograph (Figure 10a) is the gentle rise in the recession limb which peaked on July 6. This crest segment was the result of series of precipitation run-off events originating in the Liard-Mackenzie River basins from June 19 to 28 (Environment Canada 1985, 1986). Coincidentally, the water velocity showed a steady decrease from an average daily value of 0.35 to 0.18 m/sec, while the average daily water temperature rose from 9.7°C to 13.8°C. The increase in water temperature is the result of warmer water entering the Delta from the Mackenzie River basin and an increase in the air temperature locally.

After the precipitation run-off wave entered the Delta, a sharp drop in the continuous velocity record at the secondary channel site ensued (Figure 10b; July 7 to 11). The friction/drag on the channel bank increased as a result of the added volume of water entering the Delta after the precipitation run-off wave meandered through the Delta channel system. As the water level dropped, the velocity increased slightly but an overall downward trend persisted. The average daily velocity ranged between 0.14 and 0.08 m/sec from July 20 to August 02 (Figure 10b). The average daily water temperature fluctuated between 14.5°C and 11.3°C from July 20 to August 22. Towards the latter part of the summer, average daily water temperatures continued to decrease with the onset of freeze-up (Figure 10c).

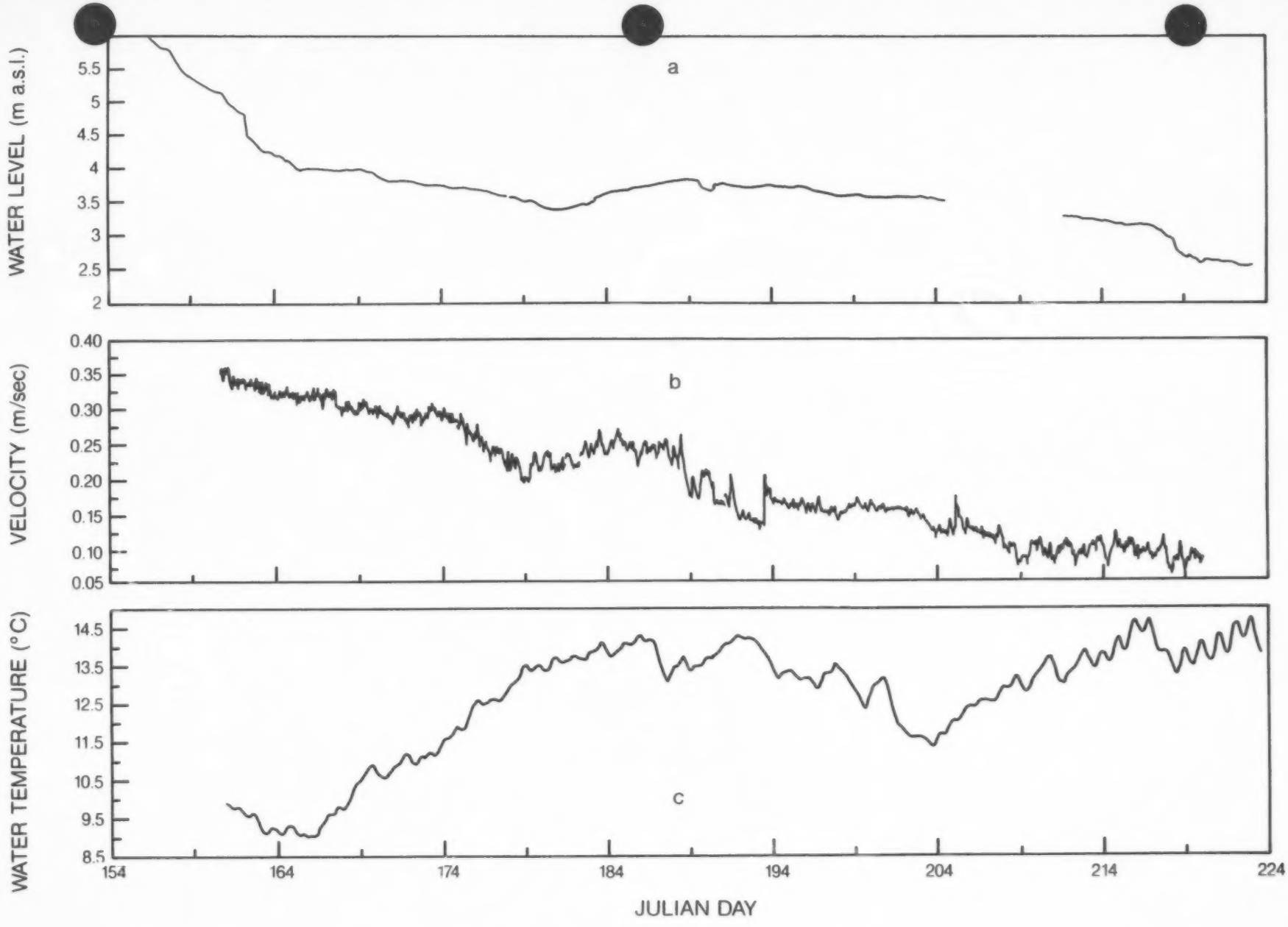


FIGURE 10: DAILY WATER LEVEL, VELOCITY, AND WATER TEMPERATURE. CHANNEL SITE, AREA 2, MACKENZIE DELTA, N.W.T., 1985.

Total precipitation during the open water period (June 23 to August 31) at Area 2 was 25.7 mm. Water balance calculations show that this was not sufficient to sustain lake water levels. Through evaporation(*), the unconnected lake loss was 330 mm, and the high-closure lake decreased by 170 mm. When precipitation for the period is taken into consideration the water loss increases to 355 mm for the unconnected lake, and 195 mm for the high-closure lake. The largest negative water balance for the summer, of all the lakes under investigation was recorded at the unconnected lake. An estimated 5213 m^3 of water was lost over the field season at a rate of 5.3 mm/d. This represents 62% of the initial lake volume for 1985 (Table 3). The lake also had the highest mean daily water temperature at 15.1°C, not out of line for such a shallow lake, (<1 metre). The high-closure lake lost on average 3.4 mm/d of which approximately 20% was due to evaporation, with the remaining 80% through surface flow. Here too the lake is shallow, with a mean mid-summer depth of 1.15 metres, and an average water temperature of 14.5°C during the summer. The average daily water temperature for the lakes were very close to the average daily air temperature of 11.3°C in Area 2 (Figure 9c).

Distributary channels in the central and northern Delta (Figure 2) have a direct-low level connection to a lake or a lake system. As such, discharge at these channel sites was as much as ten times greater than that measured at the southern distributary channel site. Discharge was measured between June 10 and August 21 at the channel site in Area 4, (Insert, Figure 4), coincidentally,

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(*) Evaporation for unconnected and closure type lakes were calculated using the Priestley-Taylor model described by Marsh and Bigras (1988a) where:
E(evaporation) = ΔS(change in lake storage) - P(precipitation)

the flow direction was always out of the lake system towards the distributary channels. Discharge fluctuated a great deal varying between 0.37 m^3/sec and 0.03 m^3/sec (Figure 8b), with an average value of 0.15 m^3/sec. The average daily water temperature was 12.0°C, slightly warmer than the average daily air temperature of 10.7°C (Figure 8b).

The connected lake lost an estimated 1.84 $x10^6$ m^3, at a rate of 17.7 mm/d, from June 23 to August 31. When the total amount of precipitation is taken into account the volume lost increases to 1.88 $x10^6$ m^3, at a rate of 18.1 mm/d. The lake volume had decreased to 73% of its maximum spring volume. Since the lake has a water filled channel connecting it to a major Delta channel throughout the open water period, evaporation(*) was not the main cause of the declining water level, accounting for approximately 17% of the total volume lost. Outflow through the distributary channel was the main source of water loss, claiming 83% of the total water volume. The average water temperature over the open water period was fairly stable (Figure 9b) with an average daily temperature of 12.7°C, 2°C above the average daily air temperature which fluctuated a great deal from 4.3°C to 16.6°C.

The high-closure lake volume had decreased to 78% of it maximum spring volume (Table 3), a decrease of 8% from its post break-up volume. When total precipitation for the open water period is taken into consideration, the total water volume lost was 17394 m^3, at a rate of 3.1 mm/d, 61% of which was through evaporation, with the remaining 39% lost through surface water flow. The

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(*) Evaporation estimates for connected lakes were obtained by using the residual of ΔS(change in water storage) - Q(discharge) = E(evaporation).

average daily water temperature was 13.4°C, just 0.8°C above the connected lake's average daily water temperature (Figure 9b).

Discharge measurements in Area 8 (Insert; Figure 6) were made ten times between June 9 and August 25. Discharge measurements ranged from a high of 0.49 m^3/sec at the beginning of the season to 0.01 m^3/sec towards the end (Figure 8c). The channel hydrograph has several small distinct peaks, many of which are also reflected in the connected lake hydrograph (Figure 9c).

There are six distinct peaks which occurred on July 6, 14, 20, 27, and on August 9 and 16. The first four are attributed to precipitation events (Environment Canada 1985, 1986b) which occurred two to three weeks earlier in the headwater area of the Makenzie River. These precipitation run-off waves require approximately 14 to 17 days to travel down-stream before reaching the channel site and increasing the water level by anywhere from 12 cm to 73 cm (Figure 8c). The other two peaks, which occurred in August, could not be traced back to precipitation events up-stream or locally. These peaks were attributed to storm surge events occurring off the Beaufort Sea coast. These storm surges were accompanied by high tide levels and brisk winds from the northwest (Environment Canada 1985; Department of Fisheries and Oceans 1985). These storm surges caused a flow reversal in the channel, while increasing its water level by 11 cm and 24 cm (Figure 8c).

The distributary channel had average daily water temperature of 12.7°C, 1.6°C higher then the average daily air temperature for the area. The distributary channel water temperature did not fluctuate as much as those

observed at the other sites during the open water period, it had a range between 10.3°C and 14.1°C (Figure 8).

The connected lake lost 1.17 x10^6 m^3 of water between June 23 and August 31 at a rate of 12.3 mm/d. A decrease of 24% since the post break-up period, increasing its total water volume loss to 90% of its maximum spring volume. During the open water period an estimated 85% of the water loss was due to water flow through the distributary channel with the remaining 15% attributed to evaporation. Fluctuations in lake level as a result of precipitation run-off events where in the order of 4 cm to 31cm. The two storm surges caused the lake level to rise by 4 cm and 7 cm.

The average daily water temperature for the open water period at both the connected and low-closure lake sites was 12.9°C. The connected lake, however, had a greater range in its daily average water temperature, 8.5°C to 16.1°C. The average daily water temperature for the low-closure lake was less variable, with a range between 11.9°C to 13.9°C (Figure 9c). The low-closure lake volume decreased by another 4% from its post break-up volume of 74% of its maximum spring volume. It lost a total of 4552 m^3 at a rate of 2.8 mm/d, 80% of which was due to evaporation with the remaining 20% lost through surface flow.

3.6 FREEZE-UP

At the onset of fall, air temperatures start to drop rapidly (Figure 7). Border ice begins to develop around lake edges first, and then on channels soon afterwards. One of the earliest occurrences of permanent ice on East

channel at Inuvik was on September 26 (Allen 1977). Lower air temperatures, higher relative humidity, continuous cloud cover and reduced sunshine hours (average of 3.5 h/d) during September and October, combine to reduce the water loss in Delta lakes late in the season. During this time there is very little change in lake levels as most lakes have reached their annual equilibrium level (Table 3), and will remain at this level until freeze-up. This is especially true for perched or closure-type lakes. The water level in these lakes is usually well below the closure elevation. As well, the water level in connected lakes is low enough at this time for the reverse deltas to act as a flow control mechanism, limiting the amount of out flow from the lakes to the Delta channels. This often saves these lakes from being drained completely. Late in October, most lake outlets in the northern and central region are frozen to the bottom, effectively preventing any further outflow from the lake. On the other hand, even when an ice cover has formed on secondary and main channels, their water level continues to fluctuate. With the commencement of snowfall, water input from the Mackenzie River Basin to the Mackenzie Delta is greatly reduced, and a corresponding reduction in the Delta channel water levels follows. Often as a result of a drop in water levels and the increased weight of the ice cover, hinge-cracks will appear along the edge of the channel. Most distributary channels, which are much shallower and smaller freeze completely to the bottom, cutting the channel off from the main Delta channels until spring break-up.

4.0 CONCLUSIONS

Several different hydrologic processes dominate the hydrological regime of lakes and channels at different periods throughout the year in the Mackenzie Delta. Lake water levels are also controlled by some of the geomorphological characteristics of the Mackenzie Delta.

In 1985 spring break-up in the Delta was thermal. There was extensive melting of the ice cover, irregular progression of the ice front downstream, short-lived ice jams and low up-stream water levels. In the early stages, ice jammed up along Middle Channel and remained static for several days causing backwater build-up. Meanwhile ice on secondary channels was melting allowing water to run freely behind the ice jam. As a result of this release mechanism, backwater did not build-up sufficiently to flood many of the high perched lakes in the southern Delta region. Lakes in the northern and central regions of the Delta, however, were flooded as a result of ice jamming and backwater build-up during spring break-up.

Spring break-up in the Mackenzie Delta can last up to three weeks, and is the most dynamic period in the hydrological cycle of Delta lakes and channels. Ice jams produce peak water levels which would not ordinarily be recorded in the Mackenzie Delta as a result of the spring run-off wave alone. Backwater flooding of lakes and channels during this period causes water levels to rise rapidly and attain their annual peak.

Two distinct mechanisms emerge as controlling lake water levels during break-up. The dominant process is backwater flooding as a result of ice jam

formation, the other is lake closure elevation. Levee heights decline from about 10 m a.s.l. in the southern Delta to less than 2 m a.s.l. in the northern Delta. Lakes located in the southern Delta are sometimes elevated several meters above the surrounding Delta channels, even though they may be connected by a distributary channel. These lakes sit atop levees which are not overtopped on an annual basis during break-up. Whereas, connected and closure-type lakes in the central and northern Delta were, and have been, flooded during spring break-up, even during low water years (Bigras 1987).

The volume of water contained in the lakes located in the central and northern regions of the Delta increase by 204% to 334% above their mid-summer lake volumes as a result of the spring flood in 1985. Connected lakes in the central Delta have the most dramatic water level fluctuations. They also have elevated levees surrounding them, between 3 and 6 metres above sea level with low water filled channels linking them to the main channel system throughout the open water period. These lakes hold large amounts of floodwater before it reaches the top of the levees and spills over. This scenario, however, does not apply to lakes in the northern Delta. Levees in this region are less than three metres above sea level and are frequently overtopped.

Lakes located in the southern region recorded volume increases of up to 74%. Unlike the other lakes, lakes in the southern region depend upon contributions from snow-melt run-off. However, much of the available snow-melt from the lake catchment is lost through infiltration and evaporation. As a result, on average only 13% of the available snow-melt reaches the lakes as run-off increasing lake levels by only a few centimeters (Bigras 1987).

The post-break-up period is marked by a rapid decline in lake and channel water levels as ice jams fail and the break-up ice front surges downstream towards the Beaufort Sea. During this period, outflow is the dominant process in the hydrological regime of Delta lakes, with lake closure elevation also controlling lake levels.

Lakes in the central and northern regions of the Delta have lost between 30% and 70% of the water volume gain during the spring flood in just three to four days. Elevated lakes in the southern Delta do not have the dramatic increases in water level as those experienced in the central and northern regions, nor are they subjected to dramatic water loss. Only about 17% of the water volume gained during the flood was lost through outflow.

During the open water period, depending on the lake type, the dominant process governing water level can be either outflow or evaporation. For the most part, change in the lake levels of unconnected and closure-type lakes in the Delta are controlled by the rate of evaporation. Lake water balance studies of closure and unconnected lakes in the Delta have shown that the evaporation from the lake surface is greater than the total precipitation for the summer months (Marsh 1986 ; Bigras 1987; Marsh and Bigras 1988a, 1988b). They also act as heat sinks, daily average water temperatures ranged from 11.9°C to 15.1°C, from June 23 to August 31. These lakes also had a negative water balance, losing between 193 mm to 330 mm during the summer, 60% to 85% through evaporation and the remaining 15% to 40% through outflow. The amount of water lost was greater than the total annual precipitation recorded in the Delta during 1985. Under these conditions unconnected and closure type lakes would probably dry up if they were not flooded during spring break-up. A case

in point is the unconnected lake in the southern Delta which is presently drying up, as it has not been flooded since 1982 (Bigras 1987).

The hydrologic regime of connected lakes during the open water season is not as straight forward as that of the perched lakes (i.e. closure and unconnected lakes). Evaporation is important but it is not the dominant process responsible for declining lake levels. Because they have a direct low water connection to Delta channels, these lakes continuously exchange water with the main Delta channels, and respond to hydrometeorologic events originating up-stream in the Mackenzie Delta basin. Storm surges accompanied by northwesterly winds which move into the Delta from the Beaufort Sea also cause connected lake levels to rise in the northern Delta (Bigras 1985). Their influence has been known to extend as far south as Inuvik (Henry 1975; Bigras 1987). Consequently, the water level of these lakes fluctuates a great deal over the summer months. A break-down of lake balance componants shows that 86% of the total water lost was through outflow, with the remaining 14% as a result of evaporation.

Water levels fluctuate continuously at distributary channel sites. Linkages between channel systems ensures that they will respond to hydrometeorological events originating further up-stream in the Mackenzie River basin. Most level increases recorded at the southern site are halved by the time they reach the northern site 24 to 30 hours later. The effect of tidal fluctuations does not extend much beyond the northern Delta (Henry 1975). Storm surges combined with northwesterly winds also effect channel levels and can cause flow reversal as far up-stream as Inuvik (Henry 1975; Bigras, 1987).

In the fall, prior to freeze-up, lake levels tend to stabilize, returning to their an annual equilibrium level which varies only slightly from year to year (Table 3) at perched lake sites. Channel and connected lake water levels (Table 3) vary annually, and are generated as a result of local hydrometeorologic conditions prior to freeze-up.

The importance of establishing a reliable data base is essential when attempting to correctly and responsibly assess potential environmental impacts. The work and analysis of data collected over the last five years has contributed a great deal towards understanding the processes which control the hydrologic regime of lakes and channels in the Mackenzie Delta. If river regulation of the Mackenzie main stem does occur, the environmental and ecological nature of the Delta will be altered. The most vulnerable region is the southern Delta. Lakes in this region have a negative water balance and cannot be sustained solely through annual precipitation. They require spring flooding for replenishment, otherwise they will dry up. Further study of lakes in Area 2 may reveal the frequency of lake flooding required to prevent lakes from drying up.

Although lakes are seen as the forbearers of change, channels are not completely exempt. With low water levels prevailing late in the field season, many of the channels risk being cut off. Late in the season, water levels in Middle and East channels are often so low that barge traffic is not possible. Nor are channels exempt from drying up. In the southern Delta many of the ditributary channels are fed by the lakes. If lake levels were to remain below their closure level, outflow from the lakes to the channel would cease, causing secondary and main channel water levels to drop. A significant decline in main

channel water levels could result in flow redistribution, altering the main channel system of the Delta, and creating similar environmental and ecological problems as those described by Muzik (1985) for the Peace-Athabasca Delta.

Recent studies have contributed new information about processes involved in the hydrological regime of Delta lakes, but more research is needed to integrate future regional development with effective management and preservation of the Mackenzie Delta. Reliable stage flood relationships are required for the Delta. A good flow distribution model which would allow the simulation of the effects of flow diversion in the Mackenzie Delta during spring break-up is also a necessity. Such a model could be used to predict the extent of flooding in the various Delta regions. With this type of information, the serious ecological and socio-economic changes which often accompany low water levels as a result of river flow regulation can be avoided in the Mackenzie Delta.

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TABLE 1
SPRING ICE LEVELS (m a.s.l.)

	AREA 2				AREA 4				AREA 8			
	1982	1983	1984	1985	1982	1983	1984	1985	1982	1983	1984	1985
Dist. channel	2.20	2.00	1.90	2.88		1.75	1.39	2.22	-0.51	0.02	0.15	0.24
Connected lake						1.19	1.56	1.67	1.02	0.31	0.64	0.27
Low-closure L.									1.73	1.57	1.77	1.44
High-closure L.	6.74	6.65	6.73	6.76		3.66	3.74	3.82				
Unconnected L.	7.64	9.02	8.53	8.23								

TABLE 2
AUTUMN LOW WATER LEVELS (m a.s.l.)

	AREA 2				AREA 4				AREA 8			
	1982	1983	1984	1985	1982	1983	1984	1985	1982	1983	1984	1985
Dist. channel	1.84	2.04	3.09	2.31	1.45	1.56	2.07	1.73	-0.19	0.35	0.41	0.17
Connected lake					1.49	1.43	2.05	1.68	0.09	0.41	0.47	0.18
Low-closure L.									1.75	1.57	1.46	1.48
High-closure L.	6.63	6.62	6.69	6.93	3.77	3.78	3.79	3.52				
Unconnected L.	8.95	8.57	8.22	7.73								

TABLE 3
LAKE VOLUMES 1985

(10^6 m^3)

	Area 2		Area 4		Area 8	
	Unconn	High-clo	High-clo	Conn	Low-clo	Conn
Spring	0.009	0.102	0.066	1.855	0.020	1.033
Maximum	0.009	0.163	0.198	7.420	0.100	7.063
Mid-summer	0.004	0.117	0.189	3.206	0.039	1.599
Fall	0.003	0.115	0.042	1.869	0.021	0.905
*Annual loss	0.005	0.050	0.157	5.295	0.080	6.230

Unconn = Unconnected Lake
Conn = Connected Lake
High-clo = High-closure Lake
Low-clo = Low-closure Lake

* maximum level + total precipitation - fall water levels.